Gypsy Moth Research: 1984-1988

GENERAL

United States Department of Agriculture
Forest Service
Northeastern Forest Experiment Station
370 Reed Road
Broomall, PA 19008

Reply to: 4500

Date: February 21, 1984

Dear Colleague:

The enclosed document provides the plan of action for the extramural research portion of the Congressionally appropriated increase of funds to the Forest Service in fiscal year 1984 for gypsy moth research.

The Forest Service uses extramural research to accelerate and augment its internal research responsibilities. This document is not a request for proposals. It is an identification of research areas that are receiving emphasis in 1984 as a result of increased funding. The areas selected for emphasis were identified by scientists in an extensive planning process described more fully in the document.

The base program of the Forest Service is not included in this document; however, duplication was prevented by extensive research planning and participation by scientists of the Forest Service with scientists from academia, other federal agencies, industry representatives, state agencies and other pest management or control specialists. To avoid duplication of research supported by the Agricultural Research Service, Animal and Plant Health Inspection Service, Cooperative states, Research Service and other funding sources, representatives of these groups were full participants in the planning process.

In addition to funding the research shown in the attached document, approximately $400,000 of the increase will be used by the Forest Service to support the multi-agency Integrated Pest Management test program in Maryland, provide a program manager and administrative support for the gypsy moth program and accelerate internal Forest Service research on gypsy moth population dynamics and formulation with Gypchek.

We anticipate a scientist's review of the research results from the 1984 field season late in the fall of 1984. Subsequently, this plan will be revised to reflect the latest scientific information and opportunities.

I would appreciate any comments you might wish to make regarding any aspect of the gypsy moth research program for which the Forest Service is responsible.

Sincerely,

Denver P Burns

DENVER P. BURNS
Station Director

Enclosure

GYPSY MOTH RESEARCH: 1984-1988
Forest Service-USDA and Cooperators

I. Introduction and Background

Previous research on the gypsy moth has provided an array of tools to control outbreaks of the pest. The next logical goal of research is to gain the knowledge and develop tools useful for extending the time between blowups of gypsy moth populations and ultimately to prevent blowups.

Based on new planning and increased funding in fiscal year 1984, researchers will focus on the gypsy moth when its population levels are at low levels and how to keep the pest at low levels.

After a period of several years during which data from previous studies were analyzed and new research approaches were tested this document was developed to describe a renewed program of gypsy moth research to cover a five year period beginning in 1984. This program of research is designed to develop the knowledge and technology that will be necessary to maintain gypsy moth populations at economically and socially acceptable levels through integrated pest management techniques. This approach reflects the fact that previous research efforts have led to the registration and use of one biological and several chemical insecticides to control or suppress outbreak populations of the gypsy moth. It also reflects the fact that the gypsy moth will gradually occupy all parts of the United States where the gypsy moth can find suitable hosts. The already substantial cost of suppressing outbreaks will increase dramatically as ever larger areas of land become involved. The gypsy moth situation entered a new phase in 1981 when the pest defoliated over 13 million acres, giving us a glimpse for the first time of the potential of the insect to defoliate a geographic area so large that conventional control measures could not cope with the scale of the infestation and the cost of direct control was prohibitive.

At the same time it became clear that the gypsy moth will continue to move slowly out of the Northeastern states toward the south, midwest and west despite all efforts to constrain it. The so called "front" where the gypsy moth was moving into previously uninfested stands of hardwood trees has crossed the Mason-Dixon line and spot infestations caused by human activities flared up around the country.

Where resources were available, pest control personnel combatted the moth. These control experiences have been shared with others who were facing the moth for the first time thus accelerating the flow of information about the pest.

The level of research on the gypsy moth has been erratic in the past. The "modern" phase had its beginning in the 1960s. By 1971 it had become evident to researchers that much useable information had been accummulated about the gypsy moth. Together with new research tools and advances in handling microbial materials causing disease in gypsy moth it was thought an accelerated research program focused on gypsy moth would yield many dividends. The pace of research was increased in the early 1970s then given a major boost in 1975 with funding to support the Combined Forest Pest Research and Development Program. That program ended in 1978 after producing major research accomplishments. But it also left unfulfilled expectations--people had been hopeful that a complete solution to the gypsy moth problem would come from the program.

Funding was reduced after 1978 and scientists resumed their base programs of research on the gypsy moth. Funding increases in 1983 and 1984 have made possible the initiation of research identified in this document.

The remainder of this document will outline the planning and research direction to address the goal of developing the knowledge to ameleorate and ultimately prevent large scale outbreaks of gypsy moth.

II. The Planning Process

The research planning process for management of the gypsy moth has been moving at an accelerated rate since 1982. This planning process has involved the USDA's Forest Service, Agriculture Research Service and Animal and Plant Health Inspection Service, many universities, industry representatives and state agencies. The planning leading this report was initiated in the winter of 1982 by discussions between Denver Burns of the Forest Service and Charles Pitts of The Pennsylvania State University. This discussion resulted in a brainstorming meeting at Pennsylvania State University by scientists from many government and state agencies, universities and from the private sector. This meeting generated a short report with many ideas for future research.

Concurrently with this brainstorming meeting, the Forest Service was negotiating with a modelling firm to conduct a series of workshops with scientists, pest control specialists and policy makers to produce a document that would help identify and evaluate important research questions or gaps in existing knowledge about the gypsy moth. This aspect of the planning was completed and the final report submitted to the Forest Service in August 1983.

With the aid of the PSU report, the modelling report and other internal Forest Service reports, a small team met and put together a working document to serve as a framework for future gypsy moth research. This document, composed of seven research objectives has been widely circulated and comments from numerous sources have been received. A writing team for each objective was appointed to expand and modify, if necessary, the research plans for 1984. This approach gave a broad base of ideas in the research plan and also prevented duplication of accelerated research efforts with the base research program already underway in the Forest Service. By keeping the planning efforts widely publicized, we have been able to develop long range plans that builds on existing research efforts. Each team contacted scientists from many organizations and incorporated their suggestions where feasible into the research working document for 1984. This document includes objectives, estimates of time needed and estimates of cost per year for research needed to be conducted in addition to the Forest Service's base program. The ensuing report elaborates on our working document for 1984. Appendix A lists the people who were conducted for input or who participated in one or more of the planning activities. We anticipate the research plan will be reviewed, updated and refined each fall or winter based on research findings and cost refinements.

Objective 1. Determine the Effects of Gypsy Moth on Forests

Until recently the gypsy moth was not considered a major pest of commercial forests. Now however the gypsy moth has moved into areas of forest land that provide fiber for many wood using industries. The tree mortality associated with recent defoliations means the activities of the pest are a direct economic concern to landowners providing wood fiber from their land and to the economic health of many companies. As the pest spreads south and west, most of the area that will be infested is commercial forest land. For these reasons a major objective of the research program is to more completely measure the impact of the pest on commercial forests, determine the steps resource managers can take to minimize mortality and growth loss, develop the economic tradeoffs among various management options, and develop the basis for determining gypsy moth impact in forests susceptible to but not yet affected by the pest.

Approach 1.1 Develop tree growth and mortality functions to predict economic loss and guidelines for intervention against gypsy moth.

A forest growth model is a major component of the overall gypsy moth life system model. When refined, the overall model will be an invaluable tool for evaluating control strategies and specific tactics for controlling the abundance of the gypsy moth. Which forest growth model is used in the overall model is not important so long as it gives reasonable estimates of the growth and probability of death of individual trees, which can be inflated to estimate the volume (or biomass), basal area, and stem density of the forest tract. The forest growth model also must estimate foliar biomass to drive the gypsy moth life system model.

The most promising approach is to modify an existing forest growth model (such as FORET) so that effects of gypsy moth can be estimated. This approach requires only that we parametrize the estimators of tree growth and probability of tree mortality. The development of estimators of tree mortality will require a data-gathering effort. A large number of data already exist which were gathered from stands devoid of gypsy moth influence. Gypsy moth life system modelers will interact with growth and yield specialists to design and parametrize estimators suitable to both which require little or no (immediate) additional data gathering.

1.1.1 Study- Parametrization of estimates of tree growth.

Parametrization of estimators of tree growth work will proceed in conjunction with the refinement of the overall gypsy moth life system model. The work will be undertaken in two stages. First, modelers of the gypsy moth life system, together with growth and yield specialists, will determine where useful growth data are located, what variables can be included in growth and mortality estimators, and, finally, design tree growth estimators that both groups can utilize. Second, the growth and yield specialists should fit the estimators with their data. Gypsy moth modelers should perform sensitivity analyses to determine whether data gathering and fine tuning of the estimators are necessary. Fine-tuning would be necessary if optimal strategies/tactics change when uncertain parameters are altered in the overall model.

1.1.2 Study - Effects of gypsy moth defoliation on mortality of trees by site and species composition.

The effects of gypsy moth defoliation on mortality of trees by site and species composition needs to be determined. Mortality functions are an integral component of growth-yield models and since gypsy moth directly or indirectly causes mortality over and above that normally expected, this must be accounted for when modelling defoliated stands. Thus defoliation-related mortality functions are needed to develop the forest model.

In a more operational context, estimates of gypsy moth-induced mortality (vulnerability) and growth loss are needed by forest land managers to facilitate decision making concerning short-term actions that are needed to minimize losses from gypsy moth.

Gypsy moth-induced mortality data should be determined from plots established over a range of forest conditions representing stands of economic value, substantial extent, and susceptible forest types. Essentially, these are on better sites (site index 60 and above) and in the Appalachian oak, mesophytic hardwoods and oak-hickory forest types.

Research is needed in the previously mentioned forest types with specific studies being geographic replications to determine if the factors accounting for mortality differences are the same in different areas. Plots will be established in stands with a prior history of significant (70%) defoliation. Growth and mortality of trees in these stands will be compared to that of similar undefoliated stands, and these plots should be remeasured annually for several years. Data from sampled stands should include mortality, ring width, age, species composition, aspect, slope position, soil depth, stand density, site index, tree condition class, crown class, defoliation intensity, understory composition, etc. Research to

examine wood utilization of gypsy moth-related mortality could be accommodated in these studies since accurate records on mortality will be available.

Data analysis should produce mortality functions to be used with the growth functions developed in element 1.1.1 to produce the forest model. Separate analyses should be used to develop forest vulnerability ratings for direct application by forest land managers. Vulnerability data are needed as a decision-making tool for forest managers, particularly for forest managers on the perimeter of the advancing gypsy moth infestation zone.

1.1.3 Historical data may be available for analysis to provide a quick estimate of the effects of various silvicultural treatments on mortality caused by the gypsy moth. To provide refinements of the initial findings will require long term plots to evaluate the most promising silvicultural practices.

1.1.3.1 Study - Stratified sampling of mortality by site class, silvicultural practices and defoliation.

The Tuscarora State Forest, a 90,000 acre forest management unit in south-central Pennsylvania, has had at least 20 years of silvicultural manipulation. It has just completed one gypsy moth defoliation cycle (1981-1983) with tree mortality now occurring. A stratified sampling of mortality by site class, silvicultural practices, and defoliation would enable an analysis of the interaction between these variables and provide information on the potential of silvicultural practices for minimizing gypsy moth effects. Similar analyses may be done on other large management units such as the Moshannon State Forest in Pennsylvania and areas in southern New York and in New England.

1.1.3.2 Study - Test promising silvicultural controls.

Promising silvicultural controls will be applied to confirm and refine the preliminary results obtained by expost analysis in 1.1.3.1.

1.1.4 When silvicultural options are developed the decision to use them will depend on an array of economic factors reflecting stand values, markets and other criteria. The basis for economic intervention needs to be developed and put in a form suitable for incorporation in the gypsy moth model and for ultimate use by landowners.

1.1.4.1 Study - Economic values for mortality losses.

After vulnerability ratings (mortality functions) have been developed, economic values can be assigned to the trees and stands and losses calculated for both trees and stands, in accordance to the products produced and markets available for those products. Most of the variables required to do this are already available as long as quality data on the trees has been collected. This information would then be incorporated into the forest model.

1.1.4.2 Study - Establish Treatment Cost

After silvicultural practices to minimize gypsy moth effects or silvicultural, biological and/or chemical methods to reduce significance of mortality-causing organisms have been identified, then treatment costs can be calculated for them. These costs and effects would then be incorporated into the forest model.

1.1.4.3 Study - Determine economic values for growth & quality loss.

After growth and quality loss functions have been developed, economic values can be assigned to the trees and stands and losses calculated in a manner similar to the mortality functions in part A. This information would then be incorporated into the forest model.

Approach 1.2.1 Develop understanding of mechanisms affecting susceptibility or vulnerability of stands to gypsy moth attack.

With the exception of low-vigor suppressed trees, most defoliation-related mortality is due to either two-lined chestnut borer (Agrilus bilineatus) or shoestring rot (Armillaria mellea). Basic studies determining the relative importance of these mortality agents as related to site-stand conditions will aid in the development of strategies designed to reduce mortality. If we know when and where secondary organisms should be a problem, such as at Tuscarora State Forest, these stands could be treated preferentially.

1.2.1.1 Study

Determine mortality of trees due to shoestring rot and two-line chestnut borer.

1.2.1.2 Study

Evaluate the relationship of gypsy moth vulnerability to inoculum potential for two-lined chestnut borer and shoestring rot.

Approach 1.2.2 Foci as sources of gypsy moth outbreak

It is hypothesized that forest insects in general, and gypsy moth in particular, become abundant when their tree hosts are stressed by early-season drought, or late season flooding of root systems. It is hypothesized that gypsy moth populations emanate from certain susceptible forests, called foci, more or less continuously. The level of dispersal and the survivorship and fecundity of larvae that disperse is probably increased when widespread weather phenomena stress the host trees of intrinsically resistant stands. We should determine whether these hypotheses are correct. Coincidently, we could try to identify foci and attempt preemptive management with the aim to prevent outbreaks. This work will require innovative design with input from sampling experts, modelers, tree biologists and entomologists.

1.2.2.1 Study - Do Foci exist

Testing the hypothesis will require scientists to develop efficient procedures to sample such things as:

- foliar chemistry, especially proline, total amino acid, total free sugar
- gypsy moth abundance, dispersal, survivorship, and fecundity
- soil moisture, tree water status, precipitation and other climatic variables.

Monitoring dispersal from a focus may require that the surrounding area be treated to eliminate gypsy moth so that immigration can be sampled.

Approach 1.2.3

Control of the agents that cause tree mortality such as the two-lined chestnut borer and shoestring root rot may provide an economical means of preventing mortality to valuable trees or stands in the face of a general outbreak of gypsy moth. Such controls may be particularly useful along the "front" as the gypsy moth first moves into susceptible stands.

1.2.3.1 Study

Evaluation of silvicultural practices to reduce mortality-causing organisms can be conducted on the same long-term plots used in other studies. The effects of silvicultural practices on inoculum potential of A. mellea and population levels of A. bilineatuswould be evaluated by sampling these variables in the 1.1.3.1 plots.

1.2.3.2 Study

Evaluation of biological and/or chemical methods of reducing mortality-causing organisms can be conducted immediately in laboratory and small field plot experiments. Promising treatments identified in the preceding experiments can also be tested in combination with silvicultural practices on separate small field plots or in conjunction with the long-term plots.

Objective 1. Determine the effects of Gypsy Moth on forests.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding in 1984
1.1 Develop tree growth and mortality functions.						
1.1.1 Parametricize estimators of tree growth	8	-	-	-	-	*
1.1.2 Effect defoliation on mortality by site and species	120	60	60	60	60	*
1.1.3.1 Examine silvicultural options	50	50	50	-	-	*
1.1.3.2 Test promising silvicultural practices	-	250	250	50	50	
1.1.4.1 Assign economic values to mortality losses	-	10	10	10	-	
1.1.4.2 Treatment costs.	-	-	-	10	10	
1.1.4.3 Assign economic values to growth and yield losses	-	-	10	10	10	
1.2 Understand mechanisms affecting stand susceptability or vulnerability.						
1.2.1.1 Mortality due to secondary agents	30	30	30	-	-	*
1.2.1.2 Determine defoliation vulnerability to inoculum potential of secondary agents	30	30	30	-	-	

Objective 1. Determine the Effects of Gypsy Moth on forests (Continued)

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding in 1984
1.2.1.3 Determine if defoliation effects inoculum density of secondary agents	30	30	30	30	-	
1.2.2.1 Outbreak initiation	50	50	50	50	50	*
1.2.3.1 Silvicultural tools to reduce secondary organisms	-	50	50	50	50	
1.2.3.2 Biol/chem. control methods for secondary organisms	25	25	25	25	25	

III. Objective 2. Improve understanding of the biology and population dynamics of gypsy moth.

The research themes proposed to attain this objective are varied and require inputs from all of the other 6 objectives of this program. The major emphasis is on the biological processes influencing gypsy moth and not just trees and stands.

A variety of preliminary research results suggest that population reservoirs may exist which serve as foci for population expansion with resulting outbreaks. If the presence of foci can be verified, research can be directed to understanding how and why the gypsy moth survives in such areas and the mechanisms that trigger or allow populations to build up and expand into other areas. If reservoirs do not exist and the pest population explodes across large geographic areas the research necessary to manage populations will be much more complex.

The concept of population reservoirs posing as "foci" from which areawide outbreaks emanate needs to be verified. More critically, since gypsy moth can be found in these reservoirs despite low regional abundance, they would ensure that the insect could be found and researched under sparse population densities. Establishing a series of study areas in which to conduct a variety of research studies has the advantage of increasing interaction and coordination between research objectives. Sharing resources in study areas maximizes efficiency and ensures coordinated team approaches and should be extremely beneficial to modeling efforts and results. Six study areas are recommended, three of which have up to 5 years of gypsy moth research background; Bryant Mountain, VT, North Stonington, CT (the plot from which the model for gypsy moth was developed), and Cape Cod, MA. Three additional sites would need to be chosen and it is suggested that these be located in West Virginia, Pennsylvania, and Virginia or Maryland.

A continuing problem has been the inability to link the results of various sampling schemes with actual population densities. Recent work by researchers at Hamden, Connecticut has provided preliminary information that needs to be expanded.

2.1.1 Develop adequate sampling procedures for all stages of the gypsy moth.

Adequate sampling methods to monitor changes in gypsy moth population density of each life stage is a prerequisite for any research aimed at enhancing our understanding of gypsy moth population dynamics and determining the relative importance of various sources of mortality. In addition, sampling methods are a critical component of gypsy moth IPM programs. The sampling procedures used by land managers are necessarily less intensive than sampling for population dynamics studies. We need to develop intensive sampling methods particularly for larvae and pupae that can be used on a small number of plots to help elucidate the complex interaction of different sources of mortality and other factors that determine gypsy moth population dynamics. In addition, research is needed on sampling methods, particularly burlaps or bark flaps, pheromone traps and egg mass counts that will provide the best information for the least cost for use by land managers.

2.1.1.1 Study - Accurate sampling schemes for larvae and pupae

Develop and evaluate methods of sampling gypsy moth larvae and pupae by comparing results of burlap band-bark flap samples with foliage samples and quadrant samples employing pyrethroid knockdown techniques. Determine optimal burlap-bark flap techniques and the factors which influence the number collected beneath burlap-bark flaps and the extent to which mortality and sex ratio beneath the flaps is representative of the population as a whole.

2.1.1.2 Study - Link trap catches of adults to other life stages

Adult samples: Determine how pheromone baited traps can be used to predict subsequent egg mass density and what factors other than density will influence trap catch. Determine whether adult sex ratio can be predicted or measured using burlaps and combined with pheromone trap catch information to predict egg mass density. Determine what factors influence the distance that males fly prior to capture in traps.

2.1.1.3 Study - Sampling egg masses

Egg mass counts: Evaluate various alternative methods for counting egg masses and the impact of various factors on egg mass distribution. Develop methods to measure egg mass size on quality and determine if such methods can be combined with egg mass counts for improved predictions of subsequent larval populations.

2.1.2 Characterize the biological processes influencing gypsy moth populations in susceptible population reservoirs.

Certain discrete forest regions are more susceptible to defoliation than others. These may serve as foci from which area-wide outbreaks emanate. Should this be true, it could be feasible to identify such sites and apply ameliorative action to suppress populations in foci before they infest adjacent forests. Studies in such an area in Vermont have demonstrated that the predator community is less diverse in foci than adjacent resistant stands, but knowledge of other factors, e.g., gypsy moth behavior, density and influence of other controls are lacking. Population reservoirs (foci) offer the opportunity for team research, model validation and if intervention is necessary, to do so on limited land area.

2.1.2.1 Study - Moth populations in suspected focal areas

Determine the status of gypsy moth population numbers over time within and adjacent to 6 focal regions selected from (VT, MA, CT, PA, VA and WV).

2.1.2.2 Study - Evaluate effects of parasites, predators and disease

Evaluate the role of disease, predators and parasites in gypsy moth population dynamics of these same regions.

2.1.2.3 Study - Host role in focal areas

Ascertain the importance of host type condition and nutritional composition within and outside foci.

2.1.2.4 Study - Relationship of other defoliators to gypsy moth

Determine how the population dynamics of native lepidoptera relate to gypsy moth, i.e., trends, biocontrols, sampling, host effects.

2.1.3 Ascertain the effect of environmental parameters and gross climate upon gypsy moth behavior and survival.

The behavior of gypsy moth appears to be directly influenced by its abiotic environment. Behavioral response has survival value and is based upon physiological function. Stand climatology can be directly altered by silvical treatments which in turn may change insect behavior and survival. The behavior and/or survival for gypsy moth over the potential range in North America is critical both to infested regions and those uninfested or with isolated infestations. To address these problems the following research is necessary:

2.1.3.1 Study - Physical environmental variation

Determine the physical environment variations in gypsy moth niches at each stage of its life cycle. Develop and field test a numerical energy balance simulator model detailing the physical effects of changes in tree crowns or canopy characteristics on the local environment. Use the model to examine the range of possibilities to change the gypsy moth's physical environment.

2.1.3.2 Study - Link gross climatic historical effects and gypsy moth population dynamics.

Establish the relationship between gross climatic parameters and gypsy moth population dynamics from time series analyses of available historical population and weather data.

2.1.3.3 Study - Laboratory determination of niche environment

Establish, under laboratory conditions, rates for metabolism, respiration, and temperature and develop a climate space model for gypsy moth.

Determine the physiological and behavioral response of gypsy moth to

variation in its physical and food environment. Develop a gypsy moth energy budget/climate space model to analyze the effects of various physical and food environments of the long term population dynamics of gypsy moth.

2.1.4 Understand the physiological relationship of gypsy moth to its hosts.

Gypsy moth responds variously to the type of host and/or condition of its foliage. These relationships may be reflected in decreased weight of larvae, pupae, and eggs, extended development time, or increased mortality. Additional impacts occur at the third trophic level; constituency of foliage can have dramatic consequences on expression of disease and susceptibility to parasitism. Host manipulation (silvicultural treatment) can modify species composition, density and chemical composition of host foliage which in turn may alter physiology and behavior. An understanding of gypsy moth-host relationships is fundamental to predicting population trends, prescribing silvicultural treatments and developing and interpreting sampling methodology.

2.1.4.1 Study - Quality and quantity of foliage

Define factors that determine the quality (and its relationship to quantity) of foliage as food for gypsy moth, how these factors vary, and what influences this variation, and the impact of foliage quality/quantity on population dynamics.

2.1.4.2 Study - Energy budget

Develop an energy and nutritional budget for gypsy moth and relate it to larval behavior, survival and fecundity of adults.

2.1.4.3 Study - Foliage quality influence on NPV and parasitism

Determine how qualitative constituency of foliage affects gypsy moth susceptibility to NPV and parasitism.

2.1.4.4 Study - Atmospheric pollutants effect upon foliage quality

Determine how atmospheric pollutants influence host tree physiology and in turn, gypsy moth herbivory.

2.1.5 Understand dispersal; propensity to disperse, how far, redispersal, and initiation of feeding.

First instar larvae are the major means for natural redistribution. While dispersal on flat terrain is principally allocated to several hundred meters, there is a need to determine dispersal distances from mountainous terrain, the role of population quality in dispersal propensity, redispersal cues and factors

which relate to initiation of feeding. Late instar larval dispersal while believed to be limited to a matter of meters under sparse populations is important to the development of accurate sampling procedures. Adult dispersal is likewise essential to accurate interpretation of trap captures whether for detection, monitoring or control purposes.

2.1.5.1 Study - Movement of late instar larvae

Ascertain II-VI larval movement and pupal location within sparse to moderate populations, detect shifts in behavior relative to population density and forest site type.

2.1.5.2 Study - First instar dispersal

Determine factors which mediate first instar larval dispersal and develop means to quantify dispersal in relation to population fitness.

2.1.5.3 Study - Relate egg mass location to pupation location and female movement.

Define the relationship of pupation locations and female movement, pre- and post-mating, to egg mass location.

2.1.5.4 Study - Relate adult male density to egg mass density

Determine the relationship of adult male density to the density of egg masses in the environment.

Objective 2. Improve understanding of the biology and population dynamics of gypsy moth.

Approach Element	Estimated Funding (1000/yr)					* High priority for funding 1984
	1	2	3	4	5	
2.1.1 Development sampling procedures						
1. Larvae and Pupae	55	55	55	55	55	*
2. Adults	25	25	25	25	25	
3. Egg Masses	15	15	15	15	15	
2.1.2 Characterize biological processes in population reservoirs						
1. Determine status of population numbers	35	35	35	35	35	*
2. Evaluate effects of parasites, predators and disease	45	45	35	35	35	
3. Host type within and outside foci	15	15	15	15	15	
4. Population dynamics of native lepidoptera in foci along with gypsy moth	10	10	10	10	10	

Objective 2. Improve understanding of the biology and population dynamics of gypsy moth. (Continued)

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding 1984
2.1.3 Ascertain environmental and climate effects						
1. Physical environmental variation	30	30	30	30	30	*
2. Gross climate historical effects	15	15	-	-	-	
3. Laboratory determination of niche environment	30	30	20	15	15	
2.1.4 Physiological relationships to host plants						
1. Quality and quantity of foliage	35	35	35	35	35	*
2. Energy budget	15	15	15	-	-	
3. Foliage quality influence on NPV and parasitism	20	20	20	20	20	
4. Atmospheric pollutants effect upon foliage quality	30	30	30	30	30	

Objective 2. Improve understanding of the biology and population dynamics of gypsy moth.(Continued)

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding 1984
2.1.5 Understand dispersal, redispersal, and initiation of feeding						
1. Movement of late instar larvae and pupae	25	25	25	25	25	*
2. First instar	25	25	10	10	10	
3. Adult females and egg masses	20	20	20	20	20	
4. Adult males and egg masses	15	15	15	15	15	

Objective 3 Develop the means to utilize parasites as regulators in low level gypsy moth populations

The research proposed is necessary to better utilize parasites in regulating gypsy moth populations by understanding the parasite interaction with the host population. This includes pest management strategies which enhance parasite effectiveness.

Approach 3.1 Measure and increase mortality of gypsy moth by parasite species.

3.1.1 Study - Evaluate and improve methods of sampling parasitoids

Among the numerous problems associated with research on the parasitoids of the gypsy moth, as well as with the justification of continued research on this subject, has been the inability to appropriately and accurately assess the impact of natural enemies like parasitoids. Thus, as a first priority we urge that research be conducted on evaluating and improving methods of sampling parasitoids. Such an evaluation should include the sampling of both immature and adult stages of parasitoids.

3.1.2 Study - Determine total mortality caused by parasites

Associated with a need for research on sampling is a need for research on the accurate determination of the total mortality caused by parasitoids. It is essential that the assessment of impact include all of the various direct and indirect forms of mortality due to parasite activity, such as adult feeding and parasitoid interactions with other natural enemies (for example, enhancement of susceptibility to pathogen infection due to parasitism). The importance of this priority area is perhaps so obvious so as not to require elaboration. Nevertheless, the understanding of the population dynamics of the gypsy moth simply cannot be accomplished without appropriate methods of assessing a key mortality factor like parasitoids.

3.1.3 Study - Evaluate effects of quantitative and qualitative characteristics of host plant on the parasitoids of the gypsy moth.

Available data have already demonstrated that the effectiveness of natural enemies is not simply a function of direct interactions between host and parasitoid but that these interactions are altered or modified by quantitative and qualitative aspects of the foliage consumed by hosts. Thus, parasitoids may respond differently to gypsy moths which have developed on different host plants. Similarly, the survival and development of parasitoids may differ in hosts reared on different

host plants. Questions of importance might include, "How does host (gypsy moth) nutrition or the allelochemicals of host plants influence parasitoids?" or "How does site species composition and/or canopy structure in field sites influence parasitism?"

It should be noted that the effects of plants on parasitoids may be direct rather than via the effects on host gypsy moth suitability or physiology. That is, plant characteristics may affect key behavior of gypsy moth hosts which in turn affect their parasitoids. Similarly, plant hosts may provide significantly different microclimatic environments which alter parasitoid survival.

The understanding of the population dynamics of the gypsy moth, the implications of stand manipulations, and the role of other natural enemies like pathogens will depend in large part on the conclusions reached from research on the effects of plant characteristics on parasitoids. Similarly, it is only with the understanding to be gained from research on subjects discussed above that we will ever be able to make logical decisions on the appropriate types of sites in which to release parasitoids.

3.1.4 Study - Determine the chemical and behavioral basis of host selection by parasitoids.

Parasite-host interaction is mediated by chemical (host, plant, and environmental) cues, host behavioral activity, and host density (functional response). Identification of the qualitative and quantitative aspects of these is an important prerequisite to assessing parasite success (reproduction/survival), and the development of means to utilize parasites more effectively. Research in this area is essential for: (1) development of parasite sampling techniques; (2) understanding the process of host selection (habitat location, host location, host acceptance, and host suitability); (3) understanding the parasite's functional response(s); (4) enhancing rearing capability; (5) enhancement of knowledge on the biology and ecology of parasite release; and (6) assessment of the feasibility of artificial manipulation to enhance parasite success (for example, use of behavioral chemicals).

Approach 3.2 Detect and collect exotic parasites as control agents in low level gypsy moth populations.

3.2.1 Study

Characterize parasite guilds presently established and effective in the U.S. (low density host populations).

3.2.2 Study - Evaluate, collect, import, and establish most promising exotic species.

Rationale for continued efforts to search for exotic parasites for use as biological control agents is embodied in most tests on classical biological control. Historically, we have utilized the "trial and error" approach, emphasizing quantity over quality. We recommend that evaluation, similar to that proposed under Approach 3.1, Studies 1 and 2, be conducted in appropriate foreign, low density gypsy moth populations. Concurrent (foreign) evaluation to identify the most effective parasites would ensure selection, collection, importation, and establishment so as to meet Objective 3.

While we feel that this is an important phase of the research, at this time we feel that efforts should be made to continue funding Approach 3.2 through USDA Scientific and Technology (IPM) cooperative agreements.

Approach 3.3 Determine the relationship between gypsy moth parasites and pathogens to increase their effectiveness.

Measurement of natural parasite/pathogen interaction is covered under Approach 3.1, Priority 2. The use of parasites for vectoring pathogens is a viable research area which was, and is presently being pursued. However, until Approaches 3.1 and 5.1 (Evaluation of Microbial Epidemiology in Low Density Populations) have been explored, further work in this area should be delayed. We recommend the evaluation of parasites as vectors be reconsidered in 2 years.

Objective 3: Develop the means to utilize parasites as regulators in low level gypsy moth populations.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding 1984
3.1 Measure and increase mortality of gypsy moth by parasite species.						
1. Sampling parasitoids	35	50	50	50	50	*
2. Determine total mortality caused by parasites	20	30	30	-	-	*
3. Effects host plant on parasitoids	70	90	90	90	90	
4. Basis of host selection	80	110	110	110	110	
3.2 Detect and collect exotic parasites as control agents in low level gypsy moth populations.						
1. Characterize parasite guilds	-	-	-	-	-	
2. Import exotic species	-	-	-	-	-	
3.3 Determine relationship between parasites and pathogens.	-	-	-	-	-	

Objective 4. Determine the role of invertebrate and vertebrate predators in low level gypsy moth populations; including necessary biology and behavior.

The research elements proposed to attain this objective are quite diverse and complex, however, realistic and obtainable. Whereas an understanding of predation was not a major component of gypsy moth management schemes for outbreak populations, its importance is greatly increased when management of low level populations is considered.

The emphasis in future research within this objective is directed toward the basic role of predation in the dynamics of the gypsy moth at low and moderate populations and the interactions of predators with other natural enemies (particularly parasites). These two research areas are essential to our understanding of forest susceptibility and application of effective IPM management of sparse populations.

Approach 4.1 Evaluate gypsy moth mortality caused by vertebrate and invertebrate predator species.

4.1.1 Study - Measure populations of predators

While many predators have been identified and some major ones studied intensively, our knowledge is far from complete in this area. As the gypsy moth invades new areas to the south and west, the predator list will change. Research is needed to establish a predator community index by habitat type whereby predation potential can be determined and related to site susceptibility.

4.1.2 Study - Assign gypsy moth mortality by predators

To assess all gypsy moth mortality associated with predators (all life stages) is particularly critical to this objective. Little is known about the risk to predation as a function of density and location of various life stages by predator species. Such understanding would have important management implications. Selected areas of high importance would be predation by ants, birds, and shrews.

4.1.3 Study - Searching behavior and efficiency of predators

Research, to determine foraging behavior and searching efficiency of predators, should be directed toward the major predators within the various predator groups. The problem here is to ascertain the probability of encounter, again as a function of prey density and location, but based on the foraging behavior of the predator (spp.). This research would also have ecological significance as it would clarify the selective advantages of the aggregation behavior exhibited by gypsy moth.

4.1.4 Study - Importance of gypsy moth in predator diets

The determination of the relative importance of gypsy moth in a predator's (spp) diet has obvious significance when examining numerical responses of gypsy moth to predator activity. Many predators appear to accept lower preference food in lieu of seeking higher preference food. This research would involve both lab and field food preference studies. This element would further the understanding of the ecological gains and consequences of aggregation and migration behavior of the larvae.

4.1.5 Study - Predator preferences among alternative foods

The proportion of gypsy moth in a predator's (spp) diet depends on abundance, availability and preference for alternative foods. Since an alternative food can significantly reduce predation of gypsy moth our ability to understand the relationships between food and selection has numerous predation enhancement implications particularly for vertebrates. It is important here to study the annual productivity (potential food-prey) in order to ascertain a sense of predictability of predation rate hence also a susceptibility relationship.

4.1.6 Study - Competition among predator species

A factor contributing to predation or affecting impact potential can be interspecific competition and interaction between predators. We have recently observed a situation where wolf spiders changed roles from predators of larvae to protectors of pupae under bark flaps by eliminating pupal predators under bark flaps. Wolf spiders are not known to be predators of pupae thereby ensuring high survival of pupae under bark flaps they inhabited. Numerous relationships exist to varying degrees among the vertebrate and invertebrate predators. A better understanding of such relationships would enhance our understanding of the role of predation in the dynamics of the gypsy moth.

Approach 4.2 Understand the interactive relationship between predators and other natural enemies of the gypsy moth.

Several studies have suggested the activities of predators may hinder or enhance the effects of various gypsy moth pathogens.

4.2.1 Study - Do predators transport pathogenic agents

Possibilities exist to enhance pathogen effectiveness in lower density populations through predator activity. Need to determine for birds, mammals and selected invertebrates the extent of their potential in this regard. Evaluate ELISA for determining environmental load.

4.2.2 Study - Determine if predator activities alter pathogen effectiveness.

The goal here is to determine if selective feeding by predators on diseased gypsy moth life stages influences the effectiveness of the pathogen within the gypsy moth population.

4.2.3 Study - Determine if predator activities modify the effectiveness of parasites

Research to determine importance of predation of parasitized gypsy moth and parasites on parasite and gypsy moth dynamics is viewed as the highest priority in this approach (4.2). Differential selection of parasitized pupae is known and potentially high rates of predation of parasites can occur. Specific parasite (spp) must be studied against predator selection. Parasite effectiveness in certain situations could be significantly reduced. Both lab and field food preference

studies will be required in order to maximize parasite efficiency in IPM. Determination of role of invertebrate predators particularly important here (i.e. ants, harvestmen).

4.2.4 Study - Effects of parasitism and pathogens on predator selection

Evaluate the effects of parasitism and disease (pathogens) on selection of healthy gypsy moth larvae and pupae by predators.

4.2.5 Study - Effects of predators on control efforts using sterile gypsy moths

Evaluate effects of predator interactions with gypsy moth sterility efforts and gypsy moth dynamics by determining the feasibility of mass release of sterile male moths. Develop release techniques which minimize predator influence. Determine effects of "seeded" sterilized eggs on predation rate of healthy larvae in populations.

Approach 4.3 Manipulate predators for enhanced biological control

The role of predators in maintaining low populations of gypsy moth is not fully known but initial modeling indicates they may have a significant effect. Predator populations are notably reduced or absent in areas tentatively identified as gypsy moth population reservoirs.

4.3.1 Study - Enhance selected predator populations

Populations of vertebrate predators, birds and mammals, can often be increased through increased availability of food and cover. Need to determine which species respond significantly to techniques such as nest boxes, brush piles, and supplemental feedings. Determine economic feasibility of management efforts. Determine magnitude of change in community predation potential taking into account interspecific consequences.

4.3.2 Study - Redistribute predators

Redistribute existing predators into new areas.

4.3.3 Study - Determine role of resource management practices on predator diversity.

Studies to determine effect of selected forest management practices and land use on predator community diversity, density and predation potential would range from the effect of various timber cutting practices including cordwood to determining the effect of domestic pest densities in rural and urban areas on predator density and effectiveness.

Objective 4. Predators of Gypsy Moth

Approach Elements	Estimated Funding (1000/yr) 84	85	86	87	88	* High priority for funding 1984
4.1 Evaluate predator-caused gypsy moth mortality						
4.1.1 Measure populations of predators	24	24	24	24	24	*
4.1.2 Assign F.M. mortality by predators	36	36	36	36	36	*
4.1.3 Determine searching behavior and efficiency of predators (birds, mammals, invertebrates)	-	-	20-60	20-60	20-60	*
4.1.4 Determine importance of gypsy moth in predator diets (birds, mammals, invertebrates)	15-45	15-45	15-45	-	-	
4.1.5 Effects of alternative foods on gypsy moth predation	25	25	25	-	-	
4.1.6 Determine interspecific competition among predators	-	18	18	-	-	
4.2 Understnd the interactive relationship between predators and other enemies of gypsy moth.						
4.2.1 Do predators transport agents of pathogens	25	25	25	-	-	
4.2.2 Do predators alter pathogen effectiveness	25	25	25	25	25	

Objective 4. Predators of Gypsy Moth (Continued)

Objectives		Estimated Funding (1000/yr) 84	85	86	87	88	* High priority for funding 1984
4.2.3	Importance of predation of parasitized gypsy moth and parasites on parasite and gypsy moth dynamics	25	25	25	-	-	*
4.2.4	Effects of parasitism and pathogens on predator selection	16	16	16	-	-	
4.2.5	Effects of predators on G.M. sterility efforts	-	15	15	15	-	
4.3	Manipulate predators for enhanced biological control						
4.3.1	Enhance selected predator populations	-	-	24	24	24	
4.3.2	Redistribute predators	-	-	-	13	13	
4.3.3	Determine practices on predator community diversity	40	40	40	40	40	

Objective 5 Determine the role of selected pathogens and develop technology to utilize them as regulators in low to medium gypsy moth populations.

Approach 5.1 Evaluate NPV, new Bt strains, selected protozoa, fungi and nematodes for regulation of gypsy moth populations.

5.1.1 - Nucleopolyhedral virus

Gypsy moth NPV disease is generally accepted to be the limiting factor in the persistence of gypsy moth outbreaks, yet the dynamics of this disease at all gypsy moth population levels are poorly understood. It is imperative to be able to predict when, where and to what degree the disease will impact on populations so that resource managers can have wider control decision options. A rudimentary NPV disease dynamics model has been developed and is being refined. Much of the model input is conjectural and model output remains untested. Research will focus on providing validated key parameter data for this model and field testing the output.

The evaluation and use of pathogens other than Bt and NPV has never been properly researched. Two nematodes and several protozoans are effective in natural European populations. Laboratory, simulated field tests, and actual field tests should be conducted in this program.

5.1.1.1 Study - Determine role of foliage, bark, litter, soil and egg mass contamination in the initiation and persistence of NPV epizootics.

5.1.1.2 Study - Determine differential susceptibility of larval stages from various geographic strains of gypsy moth to NPV.

5.1.1.3 Study - Determine degree of NPV transmission between and within generation by the actions of birds, mammals, entomophagus parasites and invertebrate and vertebrate predators of the insect.

5.1.1.4 Study - Determine the effect of gut environment biochemistry on the NPV infection process.

5.1.1.5 Study - Determine the effect of hemocoelic biochemistry on the NPV infection process.

5.1.1.6 Study - Determine factors mediating NPV entry into host cell *in vivo* and *in vitro*.

5.1.1.7 Study - Determine NPV mortality rates across a range of gypsy moth population densities and correlate with weather data to evaluate and update gypsy moth-NPV simulation model.

5.1.1.8 Study - Evaluate ELISA and refractometric methods for determining environmental and population load of natural NPV.

5.1.2 Determine if latency of NPV exists in natural gypsy moth populations and if so, its role in NPV epizootiology and how it can be utilized in population management.

5.1.2 Continued

The demonstration of viral "latency" in the gypsy moth will have a great impact on control strategies. If latency and its attendant expression mechanisms can be demonstrated, then it is likely that this knowledge can be utilized to artificially "induce" disease in gypsy moth populations, thus defusing potential outbreak populations while they are still innocuous.

5.1.2.1 Study - Determine environmental stressors, biological and physical that will induce natural virosis in gypsy moth larvae.

5.1.2.2 Study - Determine the genome or the location on the DNA that relates to virulence of the virus against the gypsy moth using restriction endonulease methods.

5.1.3 Evaluate effectiveness of new or engineered strains of Bt, such as NRD-12, HD-243 for regulating gypsy moth populations.

The commercial strain of Bt (HD-1) has been successfully used against the gypsy moth in the U.S. and Canada. It still is more expensive than conventional insecticides and has occasionally produced inconsistent results. Newly engineered or isolated strains (NR-12, HD-243) show much greater effect in laboratory tests and small field tests giving rise to the high probability of more economical, effective Bt for use against the gypsy moth and other pests alone and in an integrated sense.

5.1.3.1 Study - Evaluate selected strains (from 5.1.3.1) in field research tests in IPM program and singly.

5.1.4 Evaluate selected protozoans, fungi and nematodes for regulation of gypsy moth populations.

European gypsy moth populations are subject to significant control by nematodes and protozoa. Asian gypsy moth populations are subject to significant impact by fungi. None of these organisms has been researched and developed fully for

5.1.4 Continued

effectiveness against North American populations. The nematodes and protozoans become part of the natural enemy complex. These organisms should be imported and evaluated for their role in gypsy moth management.

5.1.4.1 Study - Evaluate effectiveness of selected protozoa, nematodes, and fungi by laboratory bioassay and simulated field tests for incorporation into IPM and field research tests.

Approach 5.2 Improve pathogen effectiveness under natural and managed conditions by broadening knowledge of pathogen distribution technology and the biotic and abiotic factors affecting effectiveness and survival.

The major limiting factor in the effectiveness of pathogens is the formulation-application-production area. Work in this area is fragmented, minimal, and not aimed at pathogen use. Three major International Symposia (1978, 1980, 1983) have identified this area as most critical in bringing microbials into functional IPM programs for managing gypsy moth and other major pest insects. The effects of various degrading wavelengths of sunlight on microbials is poorly known, the optimum distribution of the pathogens within a forested area - both applied and natural is not well understood, the methods of introduction-broadcast, spot innoculation, vectoring and baiting are poorly evaluated and known and the influence of pest density, food, temperature, humidity, other biotic entities are not well understood. The operational use of Gypchek, the gypsy moth NPV product requires a better understanding of the above factors.

New improved pathogens, genetically engineered or isolated Bts, fungi, protozoa, and nematodes all will require more thorough understanding of the form and manner of their introduction into gypsy moth populations, their effects, and their natural influence after introduction.

5.2.1 Measure and evaluate pathogen distribution patterns by conventional and unconventional techniques for optimum effectiveness.

5.2.1.1 Study - Formulations

Measure and evaluate for optimum effects of selected microbials, sunlight wavelength screens, stickers, rainfast ingredients, antievaporants, biochemical synergists and meterological events in laboratory and spray tower tests.

5.2.1.2 Study - Influence of biological factors on microbial effectiveness.

For selected microbials, measure and evaluate for optimum effects of biotic synergists, food, population quality, density and feeding rates in laboratory, spray tower, and field tests.

5.2.1.3 Study - Field tests of Gypchek formulation

Under field conditions, evaluate selected formulations, application equipment, droplet size and distribution for optimum effects of Gypchek.

5.2.1.4 Study - Model Gypchek application

Model optimum Gypchek formulation-distribution-longevity pattern methods and effects.

5.2.1.5 Study - Evaluate egg treatments

Evaluate NPV/egg mass treatment in low to medium dense gypsy moth populations - Podgwaite ongoing.

5.2.2 Study

Measure and evaluate abiotic influences, i.e. (meterology, sunlight, rain, temperature) on pathogen effectiveness and determine means to overcome deleterious effects.

New information indicates that turbulence during spraying operations is better for deposition of insecticidal material. This new approach needs evaluation and verification. Also brand new preliminary evidence is accumulating on the degrading effects of light wavelengths above the 270-300 mu range. These must be evaluated and determined for proper formulation of light-sensitive insecticidal materials.

5.2.2.1 Study - Evaluate sunlight as degrade agent

Evaluate the degrading effects of selected sunlight wavelengths on Gypsy moth NPV (Gypchek) *Bt*, and protozoa.

5.2.2.2 Study - Application factors on deposition

Evaluate the effect of turbulence and droplet size on the deposition and ultimate effect of gypsy moth NPV (Gypchek) and selected *Bts* protozoa.

5.2.3 Measure and evaluate biotic influences (natural enemy, nutrition stand type and condition, population quality, insect behavior, feeding rates) in natural and applied pathogen effectiveness and survival.

Nutrition, feeding rate, physiologic state of the pest, interactions with other natural enemies, and pest behavior all significantly affect the performance of natural and applied microbials in gypsy moth populations. Selected parasites and predators are known vectors of gypsy moth NPV, but their significance in population management is unknown - much remains to be learned.

5.2.3.1 Study - Role of Vertebrates as distributors of NPV.

Evaluate small mammals and bird as distributors of NPV and their potential to initiate epizootics.

5.2.3.2 Study - Does *B. pratensis* disseminate NPV?

Evaluate the interaction between NPV and *Blepharipa pratensis* a parasite of gypsy moth.

Objective 5. Determine the role of selected pathogens and develop technology to use them as regulators in low to medium gypsy moth populations.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	*High priority for funding in 1984
5.1 Evaluate disease agents of gypsy moth						
5.1.1 Nucleopolyhedral virus						
5.1.1.1 Role of NPV contaminated environment in epizootus	50	50	50	50	50	*
5.1.1.2 Differential susceptibility of gypsy moth strains	10	20	20	-	-	
5.1.1.3 Transmittors of NPV	25	25	25	25	25	
5.1.1.4 Role of larval gut in NPV infection process	15	15	15	15	15	
5.1.1.5 Effect of hemocoelic biochemistry on NPV infection	20	20	-	-	-	
5.1.1.6 Host cell entry	25	25	15	15	15	
5.1.1.7 Update gypsy moth-NPV simulation model	25	25	25	25	25	*
5.1.1.8 Methods to measure NPV abundance	25	30	25	-	-	*
5.1.2 Latency of NPV						
5.1.2.1 Stressors to induce natural virosis	20	20	20	20	20	*
5.1.2.2 Map virulence portion of NPV DNA	10	10	20	20	20	

Objec[redacted]e 5. Determine the role of selected pathogens and develop technology to use them as regulators in low to medium gypsy moth populations. (Continued)

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	*High priority for funding in 1984
5.1.3 B.t.						
5.1.3.1 Field evaluation of new B.t. strains	-	25	25	25	-	
5.1.4 Protozoa, fungi, nematodes						
5.1.4.1 Evaluate effectiveness of selected agents	35	35	35	25	-	*
5.2 Improve pathogen effectiveness						
5.2.1 Pathogen distribution						
5.2.1.1 Formulations	25	25	25	-	-	
5.2.1.2 Influence of biological factors on microbial effectiveness	15	15	15	15	15	
5.2.1.3 Field tests of Gypchek formulation	50	50	50	25	25	
5.2.1.4 Model Gypchek application	15	15	15	-	-	*
5.2.1.5 Evaluate NPV treatment of egg masses	35	35	25	-	-	

Object[redacted] 5. Determine the role of selected pathogens [redacted] develop technology to use them as regulators [redacted] low to medium gypsy moth populations. (Continued)

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	*High priority for funding in 1984
5.2.2 Abiotic influences on pathogen effectiveness						
5.2.2.1 Evaluate sunlight as degrade agent	75	75	30	30	-	*
5.2.2.2 Application factors on deposition	-	50	50	50	-	
5.2.3 Factors affecting pathogen survival						
5.2.3.1 Vertebrates as NPV distributors	20	25	25	25	25	
5.2.3.2 Does <u>B. pratensis</u> disseminate NPV?	-	-	-	-	-	

OBJECTIVE 6. Evaluate role of integrated pest management for gypsy moth.

Integrated pest management (IPM) of the gypsy moth is currently at an embryonic state of development. There has not been a concerted effort to truly manage the gypsy moth at a level below that which causes economic damage. Nor has there existed a system for systematically monitoring the gypsy moth when populations are innocuous and not imminently threatening to cause economic damage.

Many of the tactics and much of the technology that we discuss are in a research mode and require further evaluation. These evaluations can be conducted simultaneously with ongoing IPM pilot or demonstration projects because IPM is an iterative process that incorporates reevaluation and modification based on the annual performance of operational systems.

Approach 6.1 Develop, evaluate, and integrate tactics and supportive technology for management of gypsy moth populations.

Approach Elements

6.1.1 Utilization and evaluation of parasite species

As the gypsy moth spreads to new areas to the South and West, the more abundant species of established parasites ultimately follow behind. However, not all species disperse at the same rate nor do we know what the lag time is between establishment of host and its complement of parasites. It has been suggested that this differential in host-parasite synchronization can be reduced by inoculating beneficial species into newly infested areas where gypsy moth numbers are adequate to support their initial establishment. A study is needed to evaluate the benefits of this approach.

6.1.1.1 Study - Inoculate populations outside the generally infested area with currently established species.

Lack of alternate hosts, specifically overwintering hosts is probably one of the major causes for non-establishment of introduced exotic parasitoids. Some

alternate host studies have been conducted by several laboratories and several candidate species have been identified. More extensive evaluations are needed specifically of lepidopterous and hymenopterous defoliators that are indigenous to states to the south and west of the generally infested area.

6.1.1.2 Study - Evaluate potential alternate hosts in newly infested areas for those exotic species that have not been established in the generally infested area. 1/

During the period of accelerated research on gypsy moth (1971-1978) foreign exploration in Europe and Asia produced a number of exotic species of parasites that were reared and released in the Northeast. Despite these efforts, no new species were established. Discussions of the reasons for establishment or non-establishment of gypsy moth parasitoids suggested the following problem areas: inadequate numbers for release; genetic deterioration attributed to laboratory propagation; lack of knowledge of overwintering sites or need for alternate hosts; lack of information on diapause requirements; poor synchronization with hosts and climate in release areas.

6.1.1.3 Study - Attempt releases for establishment of exotic species in newly infested regions to the south and west.

Although many augmentative releases of select gypsy moth parasitoids have been conducted, rarely have these releases resulted in increased parasitism in successive generations. The one exception occurred when *Blepharipa pratensis* was released in New Jersey in 1978. The role of tachinids in the population dynamics of the gypsy moth has been documented and literature on the bionomics of *B.pratensis* and its propagation is available.

6.1.1.4 Study - Evaluate augmentative releases of select tachinids such as *Blepharipa* or *Compsilura*.

Since its registration, Gypchek (NPV) has been used as a classical pesticide, i.e., it has been applied aerially to protect foliage and suppress populations. Researchers believe that a better use for Gypchek might entail introducing the NPV

1/ In both cases we suggest re-evaluation of those promising exotic species that were released in the Northeast over the past 20 years.

into moderate density populations that are rapidly increasing with the intent of initiating an early epizootic and possibly dampening the amplitude of an impending outbreak. Parasites may serve as a vehicle for inoculating the NPV and laboratory research has indicated that some species are capable of transmitting the virus to healthy larvae. Small scale field trials are needed to thoroughly evaluate the feasibility of this approach.

6.1.1.5 Study - Evaluate select parasite species as vectors of NPV.

6.1.2 Utilization and evaluation of predator species

Much has been written about vertebrate and invertebrate predators of the gypsy moth however most of what is published is more qualitative than quantitative. A concensus of opinion is that predators are important in the dynamics of sparse populations in the Northeast but have little importance when gypsy moth populations are expanding rapidly.

The predator complex is diverse but varies greatly depending on the ecological characteristics of the site. We need to know which species of invertebrates and vertebrates prey on gypsy moth in newly infested regions to the South and West and to determine if any of these predator species are amenable to management either directly or indirectly through silvicultural manipulation.

In the Soviet Union and Japan, birds are regarded as important predators of gypsy moth and efforts are made to manage nesting species in forested areas.

6.1.2.1 Study - Determine the role of the following predator groups in different forest types to the South and West and evaluate potential for their manipulation.

6.1.2.1a Insectivorous birds

6.1.2.1b Small mammals

6.1.2.1c Invertebrate predators

During the period from 1906-1926, Calosoma sycophanta was imported from Central Europe and established in the Northeast. At times, this voracious species is

extremely abundant especially when populations are dense; however, we know nothing about this species and other species of Calosoma in sparse populations. The feasibility of rearing species of Calosoma for distribution and possibly for augmentation in the Northeast and in the South should be explored.

6.1.2.2 Study - Evaluate the potential role of Calosoma spp. and related Carabids in different forest types to the South and West.

6.1.3 Evaluate potential use of inherited sterility

Releases of sterile males in Michigan and South Carolina have indicated that, with favorable overflooding ratios of sterile to feral males, sparse populations essentially can be eliminated. Recent research has shown that the progeny of matings with partially sterile males are totally sterile, thus providing us with an alternative approach for interacting with feral populations. Sterile egg masses from partially sterile matings can be stockpiled in mass rearing facilities and released into native populations, thereby avoiding the logistically difficult release of sterile male moths. We need to know whether large scale releases of sterile individuals can dampen upward trends in sparse to moderate populations and then put limits (density) on this tactic. At least a 2-year period of evaluation would be required after the initial release.

6.1.3.1 Study - Determine effect of sterile egg release on the trend of sparse to moderate gypsy moth populations.

European researchers knowingly "seed" forested areas with gypsy moth egg masses when populations are sparse to provide adequate hosts for and thus enhance survival of desirable species of parasites. Releases of sterile egg masses could be used therefore to provide progeny to sustain parasites at a level higher than would otherwise occur after population crashes, and thereby possibly reduce the time required for parasite populations to respond to subsequent gypsy moth population increases.

6.1.3.2 Study - Evaluate releases of sterile eggs to augment populations of select parasite species.

6.1.4 Utilize NPV to suppress or dampen population increases.

The gypsy moth NPV has been used to suppress dense populations and to protect foliage but its utility to dampen population increases has not been evaluated. It has been suggested that NPV should work best against low to medium density populations though very little efficacy data has been derived at populations below 500 egg masses/0.4-ha. Our success in utilizing NPV to dampen populations or to initiate epizootics will depend on our progress towards understanding NPV epidemiology, virus replication and transmission, and the role of predisposing factors. Very little efficacy data has been obtained utilizing improved formulations of Gypchek since the product was registered.

6.1.4.1 Study - Conduct field trials to (a) establish dose/response data of NPV on sparse to dense populations and (b) to evaluate carryover effect in subsequent generations.

One approach to inoculating NPV into moderate density populations involves applying a formulation of Gypchek by mistblower to visible egg masses and tree boles. The objectives of this approach are to: reduce the survival of hatching larvae; increase the probability that surviving larvae will be contaminated in later instars; and enhance the transmission and persistence of the virus into subsequent generations.

6.1.4.2 Study - Evaluate pre-hatch mistblower application of NPV to understory egg masses in moderate level populations.

At least two procedures have been developed to estimate the natural virus load in populations - a refractometric method and the ELISA technique. Either procedure would be invaluable if it could be used to predict the ultimate collapse of populations or suggest that populations are healthy and expanding. Field evaluation of these techniques is sorely needed.

6.1.4.3 Study - Concurrently evaluate technology to measure virus titres in early instars.

6.1.5 Optimize use of chemical and microbial insecticides to suppress or dampen population increases.

Historically, the efficacy of registered pesticides against a target organism is determined in the laboratory and confirmed in field or plot trials. The objective of this exercise usually is to obtain maximum suppression of the pest. Often, performance of a product in the laboratory cannot be duplicated in action programs. Furthermore, in an IPM approach a less than maximum kill may be desirable. For this reason researchers have felt that replicated field dose/response trails are badly needed.

6.1.5.1 Study - Conduct field trials to establish dose/response data on B.t. and other select registered pesticides.

There is a continuing need for field evaluation of candidate insecticides that are efficacious against the gypsy moth and that possess desirable characteristics for their use in urban-forested environments. This may include synthetic pyrethroids or yet to be registered growth regulators/chitin inhibitors.

6.1.5.2 Study - Evaluate candidate insecticides and their effects on non-target organisms.

6.1.6 Combination treatments

There has been little opportunity to evaluate combination treatments in the past because (1) the efficacy of individual tactics was not determined, and

(2) application and proper evaluation of combination treatments is expensive to conduct. We suggest the following but recognize that from future analyses other combinations may be more desirable and/or practical.

6.1.6.1 Study - Evaluate applications of insecticides that retard gypsy moth larval development, followed by parasite releases.

6.1.6.2 Study - Evaluate sequential application of microbial insecticides followed by release of sterile egg masses.

6.1.6.3 Study - Evaluate application of Gypchek or Bt followed by disparlure.

6.1.7 Evaluate silvicultural practices as they affect the gypsy moth and its natural enemy complex.

Foresters have, since early in this century, recommended that silvicultural prescriptions should be used to adversely affect the gypsy moth and to reduce its total impact (growth loss and mortality) on the forest. Consideration of this approach necessitates that studies will be evaluated over the long term although the direct effects of treatments on first instars and late instars could probably be ascertained over a period of 2-3 years. The following biological evaluations should be conducted whenever silvicultural studies are initiated in forthcoming years.

6.1.7.1 Study - Effect of silvicultural treatments

6.1.7.1a Evaluate the effect of silvicultural treatments on post-dispersal survival of first instars.

6.1.7.1b Evaluate the effect of silvicultural treatments on late instar survival.

6.1.7.1c Evaluate the effect of silvicultural treatments on the parasitoid complex.

6.1.7.1d Evaluate the effect of silvicultural treatments on the predator complex.

6.1.7.1e Evaluate the effect of silvicultural treatments on the frequency and duration of outbreaks.

Approach 6.2 Develop and evaluate IPM strategy

Approach Elements

6.2.1 Evaluate the concept of "foci" to explain the incipient phase of gypsy moth outbreaks.

The existence and potential importance of "focal stands," areas where gypsy moths may persist and/or emanate from, has been discussed for many years. If such stands exist, they would obviously be prime targets for intensive monitoring and/or early management. For this reason alone, we consider this element to be top priority and have a two-pronged approach - one historical and the other manipulative.

6.2.1.1 Study - Historical outbreaks

Conduct a study of historical defoliation records from states like Massachusetts and New Hampshire to ascertain if outbreaks develop from distinct focal areas.

6.2.1.2 Study - Induce outbreaks

Develop a field study to ascertain if outbreaks can be induced in susceptible vs. resistant stands by artificially seeding populations and/or manipulating bark flaps.

6.2.2 Evaluate IPM in commercial forest

The Maryland IPM project is the first state-federal cooperative program of its kind that is attempting to manage the gypsy moth over a geographical resource area at pre-defoliating levels. Decisions about the need for treatments and the choice of tactics are made based on information provided by intensively monitoring populations on a one-kilometer grid throughout the project area. For commercially forested areas it is unlikely that this demonstration effort will provide us with a definitive answer about the merits of IPM for the gypsy moth because much of the project area is categorized as urban residential. Within this setting, the impacts associated with gypsy moth are different and the tactics available for use are restricted. The Maryland approach will be applied to commercial forest stands to satisfy the needs of managers of commercial forest land.

6.2.2.1 Study - Duplicate Maryland IPM approach in commercial forest stand.

6.2.3 Economics of IPM vs. No action

Since 1970, benefit/cost analyses have been developed to evaluate the need for and results of accelerated R&D programs, and to compare the merits of cooperative suppression programs vs. a do nothing approach. Since then, new information has accumulated on gypsy moth-related impacts, microbial insecticides have largely replaced chemicals for suppression, and priorities and attitudes of the general public have changed. In light of this, we need a thorough benefit/cost analysis

or socioeconomic model that considers IPM vs. classical suppression vs. no action.

6.2.3.1 Study - Conduct an economic evaluation of IPM approach vs. "suppression" vs. "do nothing" approach.

6.2.4 Develop and evaluate a system for monitoring gypsy moth populations.

Any future program that attempts to manage gypsy moth populations must be based on a sound monitoring network that will alert decisionmakers to impending problems. Whether one's goal is management or suppression, sufficient lead time is required to plan programs and obtain needed resources to expedite the programs. Although we have the tools available to detect and monitor gypsy moth populations, no attempt has been made to package and evaluate a practical system that will be useful to states and other user groups.

The pheromone trap is the most sensitive tool available to detect the gypsy moth when populations are sparse. Because they are relatively inexpensive to purchase and don't require labor intensive practices to deploy, the trap is the only practical device available to monitor populations over a large area. However, we need to know how male moths in traps are related to population densities in the adjacent area.

6.2.4.1 Study - Relate male moths in traps to absolute densities in egg masses or larvae.

In recent years, researchers strove to develop the most attractive lure and the most efficient large capacity trap. Ironically, this satisfies our needs to detect gypsy moth populations but may not represent the best trap/lure system for monitoring populations. In the generally infested areas, large capacity traps fill up even when populations are sparse (25 egg masses/ha) and trap efficiency may decline rapidly as traps become saturated. The trap system needs to be evaluated with emphasis placed on monitoring and not detection.

6.2.4.2 Study - Reevaluate and redesign the present trap and lure for monitoring purposes.

Objective 6. Evaluate role of IPM for gypsy moth.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding 1984
6.1 Tactics and technology to manage gypsy moth populations						
6.1.1 Utilization and evaluation of parasite species.						
6.1.1.1 Parasites into new areas	25	25	25	-	-	
6.1.1.2 Eval. alternate hosts	25	25	25	-	-	
6.1.1.3 Est. exotic spp	20	20	20	-	-	
6.1.1.4 Augmentative release of tachinids	-	50	50	50	-	
6.1.1.5 Parasites as vectors	20	20	-	-	-	
6.1.2 Utilization and evaluation of predator species						
6.1.2.1a Role of birds	30	30	30	-	-	
6.1.2.1b Role of small mammals	30	30	30	-	-	
6.1.2.1c Role of invertebrate predators	25	25	25	-	-	
6.1.2.2 Potential of <u>Calosoma</u>	25	25	25	-	-	
6.1.3 Evaluate potential use of inherited sterility						
6.1.3.1 Eval. sterile egg release	60	60	20	-	-	*
6.1.3.2 Sterile egg release to augment paracites	30	30	-	-	-	
6.1.4 Utilize NPV to suppress or dampen population increases						
6.1.4.1 Dose/response NPV in field	-	-	120	120	-	
6.1.4.2 Apply NPV to egg masses	25	25	-	-	-	
6.1.4.3 Tech. to assess NPV titers	30	30	-	-	-	*

Objective 6. Evaluate role of IPM for gypsy moth.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding 1984
6.1.5 Optimize use of chemical and microbial insecticides to suppress or dampen population increases.						
6.1.5.1 Dose/response of Bt and chemicals in field trials	-	-	-	120	120	
6.1.5.2 Evaluate new insecticides	-	-	-	45	45	
6.1.6 Combination Treatments						
6.1.6.1 Insecticide & parasites	-	75	75	-	-	
6.1.6.2 Microbials & sterile eggs	-	125	125	-	-	
6.1.6.3 NPV or Bt and disparlure	-	125	125	-	-	
6.1.7 Silvicultural Treatments						
6.1.7.1a Effect of treatments on 1st instar	60	25	-	-	-	
6.1.7.1b Effect of treatments on later instars	60	25	-	-	-	
6.1.7.1c Effects of trmts. on parasitoids	60	20	20	20	-	
6.1.7.1d Effects of trmts. on predator complex	60	20	20	20	-	
6.1.7.1e Effects of trmts. on freq. and duration of outbreaks	60	5	5	5	5	

Objective 6. Evaluate role of IPM for gypsy moth.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding 1984
6.2 Develop and evaluate IPM Strategy						
6.2.1 Evaluate concept of "Foci"						
6.2.1.1 Historical study of focal sites in New England	15	-	-	-	-	
6.2.1.2 Field study to simulate mode of action of focal sites	-	40	40	40	-	
6.2.2 Evaluate IPM in commercial forests						
6.2.2.1 Evaluate in commercial forest stands	80	80	80	80	80	
6.2.3 Economic Evaluation of IPM vs. Suppression vs. no action						
6.2.3.1 Conduct evaluation	-	-	-	30	30	
6.2.4 Develop and Evaluate Monitoring Monitoring System						
6.2.4.1 Relate male moth catch to densities of other life stages	30	30	30	-	-	*
6.2.4.2 Reevaluate trapping system for mortality	35	35	-	-	-	*

Objective 7 Develop scientific technical support for gypsy moth management research.

A stable program of activities is needed to support the research program. Scientific support provides an array of tools such as gypsy moth life stages, rearing capability, quarantine facilities and production and maintenance of the gypsy moth life system model and its submodels. Included below are the major support activities. Several of them incorporate highly applied research or methods development to assure quality control and to meet production requirements.

Approach 7.1 Develop and improve rearing technology of gypsy moth and its parasites and pathogens for research and evaluation purposes.

A fundamental need for both research and management of gypsy moth is a predictable source of insects of known quality. Uses include production of partially sterile males, virus, and parasites as well as gypsy moth for behavioral and ecological research. Additionally, primary quarantine facilities are essential for evaluating beneficial organisms prior to attempted establishment. Existing facilities at the APHIS laboratory at Otis AFB, MA, are equipped for mass culture of gypsy moth and its biorationals; Forest Service capabilities include insect production for research purposes (Hamden, Conn.) and a partially completed quarantine facility (Ansonia, Conn.). The need is principally for staff, rearing material and limited equipment to ensure that the research support is available to other objectives of the program.

7.1.1.1 Task

Provide limited gypsy moth life stages to a variety of researchers so as to avoid the costly duplication of rearing at different locations and to ensure a continuous supply of insects of consistent quality.

7.1.1.2 Task

Develop a gypsy moth strain with visible genetic markers.

7.1.1.3 Task

Determine the methodology for establishing on diet larvae which fed previously on foliage in the field.

7.1.1.4 Task

Refine existing operational rearing procedures or develop research technology to improve sex ratio manipulation, pupal harvesting and quality control of laboratory reared insects.

7.1.2.1 Task

Improve rearing and develop quality assurance methods for representative parasites (e.g., optimize reproduction and identify performance characteristics for adult competitiveness)

7.1.2.2 Task

Manipulation of diapause/stockpile parasites.

7.1.2.3 Task

Develop knowledge of alternate hosts.

7.1.2.4 Task

Genetic improvement (e.g., searching capability, rate of increase, sex ratio).

7.1.2.5 Task

Holding, transport and release technology.

7.1.3.1 Task

Produce sufficient quantities of Gypchek or virus-killed cadavers to support research and development needs.

7.1.3.2 Task

Develop or implement production technology for non-commercially produced pathogens (i.e., fungi, protozoa, nematodes) other than Bt or NPV.

7.1.3.3 Task

Produce new NPV strains (identified as more active than present strain) for evaluation and implementation in program.

7.1.4.1 Task

Stockpile gypsy moth eggs for 1985 field trial to include development of egg production technology.

7.1.4.2 Task

Study developmental synchrony and survival of F_1 sterile larvae relative to feral larvae.

7.1.4.3 Task

Develop a rearing model vs. various overflooding scenarios.

Approach 7.2 Provide quarantine facilities for research, evaluation and production of exotic pathogens, predators, and parasites.

The importance of biological control organisms in limiting gypsy moth is well known in Europe and East Asia. In many cases alternate hosts for pathogens, parasites, and predators exist which are not present in North America. For example, there is evidence that a nucleopolyhedral virus of congeneric species is more active against gypsy moth than the standard NPV strain. However, in order to pursue this more thoroughly, the congeneric species must be reared to produce the pathogen in volume. Other examples exist for evaluation of exotic parasites and predators. There is no primary quarantine facility currently available for forestry research purposes to conduct studies on exotic organisms for genetics or biological control purposes. There is a critical need for U.S. Forest Service to complete and activate its Ansonia, Conn., quarantine facility for use by its scientists and their cooperators to investigate new lines of research under the strictest controls.

7.2.1 Task

Complete the quarantine facility and produce and maintain colonies of exotic organisms and their hosts for research evaluation and production of biological control organisms for gypsy moth.

Approach 7.3 Develop iterative models for assessing and predicting gypsy moth numbers and impacts and management models for use by suppression agencies for making management decisions.

7.3.1 Task

Based upon existing and new data, modify submodels for tree stands, gypsy moth and its parasites, predators, and pathogens.

7.3.2 Task

Develop an economic cost/benefit submodel to assist managers in determining effective management activities.

7.3.3 Task

Develop information management techniques geared to local requirements but compatible with regional criteria for inclusion into the master management model.

7.3.4 Task

Integrate the biological and economic submodels into the gypsy moth master simulation model and validate it.

Object[redacted]. Develop scientific technical support for g[redacted] moth management research.

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding in 1984
7.1 Rearing technology						
7.1.1 Gypsy moth						
1. Provide insects	20	20	20	20	20	*
2. Genetic marker	-	-	-	-	-	
3. Larvae field/diet	20	20	20	-	-	*
4. Refine rearing procedures	25	25	25	25	25	
7.1.2 Parasites and Predators						
1. Improve rearing	15	40	40	40	40	*
2. Manipulation of dispause/ stockpile	10	10	10	-	-	
3. Alternate hosts	15	15	15	15	15	
4. Genetic improvement	-	-	10	10	10	
5. Holding, release technique	-	-	20	20	-	
7.1.3 Virus and Other Pathogens						
1. Production of sufficient Gypchek for research support	-	35	35	35	35	

Objective 7. Develop scientific technical support for gypsy moth management research (Continued)

Approach Element	Estimated Funding (1000/yr) 1	2	3	4	5	* High priority for funding in 1984
7.1.3 Continued						
2. Technology for noncommercial production of pathogens	-	-	-	20	20	*
3. Produce new NPV strains	-	25	25	25	25	
7.1.4 Sterile and Partially Sterile Males						
1. Stockpile eggs for 1985 field tests	40	20	-	-	-	*
2. Survival and Synchrony of F_1 males	15	15	-	-	-	
3. Rearing Model	-	10	-	-	-	
7.2 Provide Quarantine Facilities						
1. Producing and maintaining hosts and exotic organisms	50	25	25	25	25	
7.3 Develop interative models						
1. Modify submodels	35	55	55	55	55	*
2. Economic/cost benefit	-	-	-	25	25	
3. Information management local-regional	-	-	-	-	-	
4. Integrate submodels	-	-	15	15	15	

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